

FINAL REPORT

RADIOMETRIC SPECTRAL RESPONSE OF OIL FILMS

OCSEAP RESEARCH UNIT 399

P.M. Kuhn, L.P Stearns
E.S. Salazar and B.J. Loupee
NOAA - APCL - R31
Boulder, Colorado 80302

REGISTERED

INTRODUCTION

This project proposed to investigate the effects of various IR spectral pass bands on the response of an infrared radiometer in the identification and extent of simulated oil spills on sea water at different water temperatures. An attempt was made to also determine such effects on simulated oil spills of different oil thicknesses.

The IR radiometer system employed was a single channel NOAA radiometer made up as a prototype unit from parts of the electronics of commercial manufacturers but with a NOAA designed optical train. Filters for the three spectral pass bands employed were manually changed for each experiment. In view of the necessarily limited funds remaining for this experiment after the Barrow IR imager deployment for the Arctic Project Office, three pass bands were investigated. The method followed in the research was that of observing the infrared signatures of four OCS furnished oil samples with respect to type, temperature and thickness in the three pass bands.

Prior to the laboratory experiment a modest literature review was conducted. After the archival search one of the better definitive studies on an airborne oil surveillance system was that of the Office of Naval Research (1975). The multi-sensor system described consisted of a SLAR (side-looking airborne radar), passive microwave imager, low light level TV and a multichannel IR line scanner similar to the NOAA-APCL IR imager. Reported total cost of instrumentation was \$360,000. By way of contrast, the NOAA fixed field IR radiometer employed in this study has a total value of ~ \$6000. The Navy study involved deliberate

500 gallon spills in the eastern Pacific but without laboratory control. This study involved laboratory-simulated oil spills contained in limited size tanks by floating plastic containment rings. The NOAA imager, operating in the same IR pass bands as the referenced NOAA fixed field radiometer has a total value of ~ \$36000. It might have been used downstream in this study if further limited funding had been available. Both units have and will be flown on NASA jet aircraft for similar research in conjunction with NASA projects.

One may summarize, perhaps even in an introduction, by stating that to our knowledge no similar study as this involving fixed field radiometry in a precise laboratory calibration mode has come to our attention. The results directly applicable to the IR scanner show that the radiometer (or IR scanner) system can reliably detect and map oil spills as to extent and general oil type identification. Results on oil thickness determination were inconclusive. However, the overall results strongly suggest that a better base funded study with an IR spectrometer or interferometer, such as possessed by NOAA-APCL, could produce more detailed results even extending into possible restrahlen IR signatures for specific oil types and possibly thicknesses. Preliminary results obtained so far show that there may well be characteristic oil-type absorption spectra initially only identifiable by an interferometer or spectrometer. This, then, would enable the proper choice of pass band filters for later used airborne IR imagery. However this would be a six to nine month study at a base cost minimum

of \$60,000. Such figures for an in-house project were arrived at after consultation with SRI whose figure, incidentally, was \$120,000 for one year. From the point of view of physical oceanography, we suggest that it would be well worth while and urge its implementation as a dedicated project.

RADIOMETER CHARACTERISTICS

The radiometer employs-a 100 Hz gold plated optical chopper system alternately directing the signal impinging on the detector from the reference Helmholtz cavity to the target. This results in an AC wave suitable for amplification and signal processing via the preamplifier and main frame electronics.

The equation reducing the radiometer observed output voltage to radiance ($w\text{ cm}^{-2}\text{ sr}^{-1}$) is (see symbol table)

$$N_T^+ = k (G[V_o + a_o + a_1 T + a_2 T^2] - V_E) + N_R \quad (1)$$

The target radiance ideally is that radiance emitted directly from the oil or water surface. However this equation is general and does not involve surface emissivity. It is further assumed that the target fills the field of view (2° to 1/2 power points; 4.5° to the 95% power points) of the radiometer. N_T^+ is a direct function of the spectral pass band employed (i.e. 10-12 μm , 8-14 μm , . . .). The radiometer radiance minimum detectable signal ($N.E.\Delta N$) is 7.0×10^{-7} $w\text{ cm}^{-2}\text{ sr}^{-1}$.

To convert radiance to calibrated equivalent black body temperature, T, we extract the target temperature from the **Planck** function in the expression for observed target radiance.

$$N_T^t = \int B(v, T) \phi(v) \sigma(v) dv, \quad (2)$$

where N_T^t in Eq. (1) and (2) are identical.

The radiometer minimum detectable temperature change is approximately $\pm .17^\circ C$ at a target temperature of $7^\circ C$. This is directly related to the N.E.ΔN cited above.

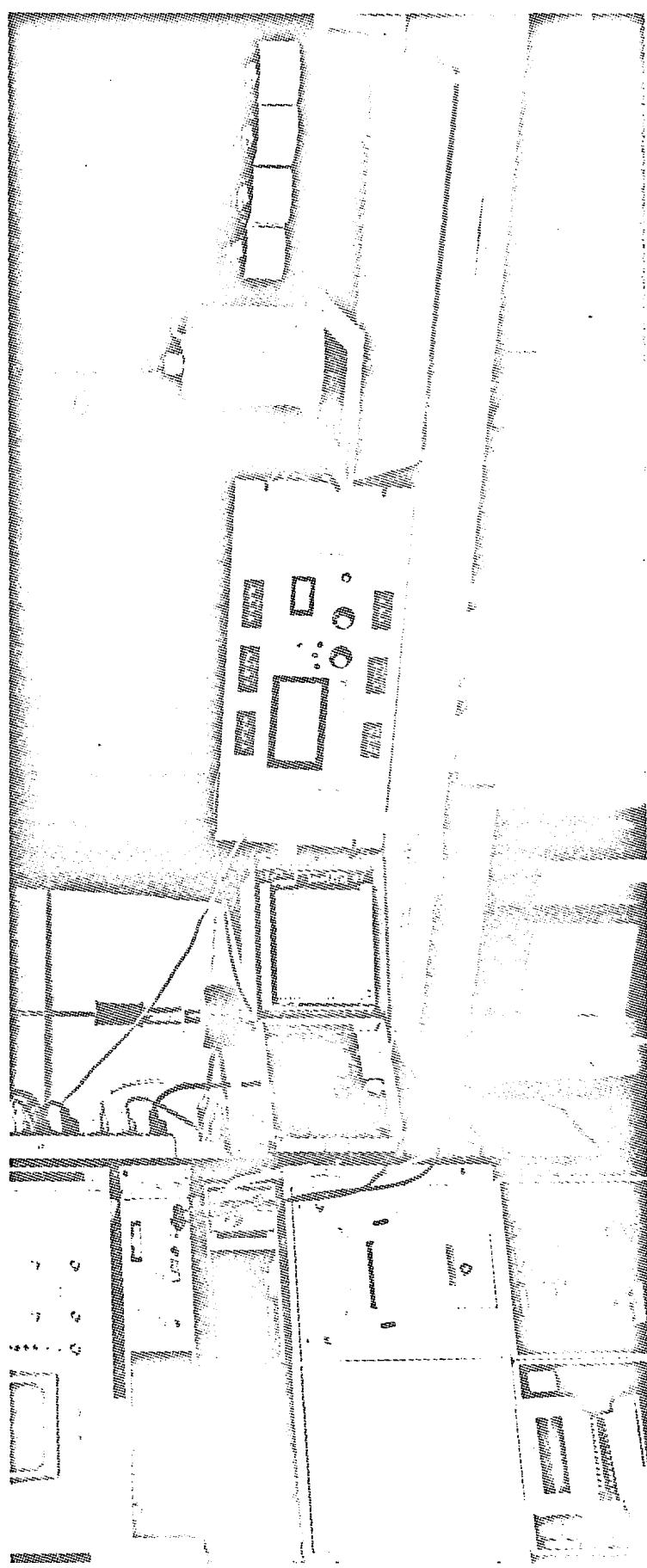
Calibration is normally accomplished by determining the system transfer coefficient, k, after observing a known source of radiation.

LABORATORY OIL SLICK INFRARED SIGNATURES

EXPERIMENTAL SET-UP

To avoid oil-water mixing in this pilot project **radiometric** observations of the infrared oil signatures were conducted in the laboratory. Fig. 1 illustrates the experimental set-up. The blackened tray contains the "simulated" sea water, and two oil samples enclosed by floating plastic containment rings. One also sees the analog and digital data recording system as well as the modified single channel radiometer". The experimental tray and radiometer instrument platform appear in Fig. 2. In Fig. 3 a filter wheel radiometer (eight channels) is in position on the instrument platform. The platform is moved to scan the contained oil and water alternately. Radiometer output is available in real time via analog and digital output.

Fig. 1



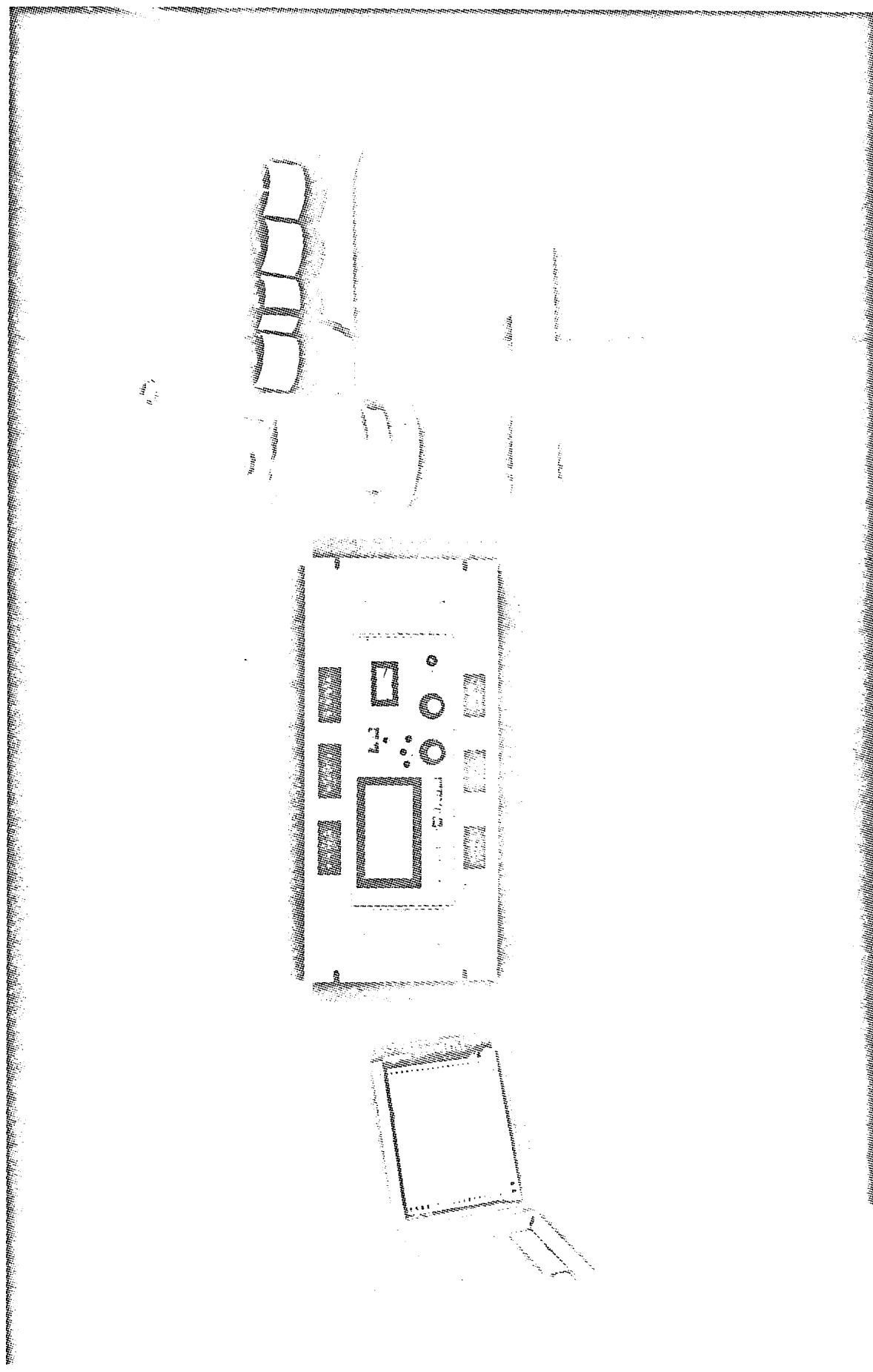
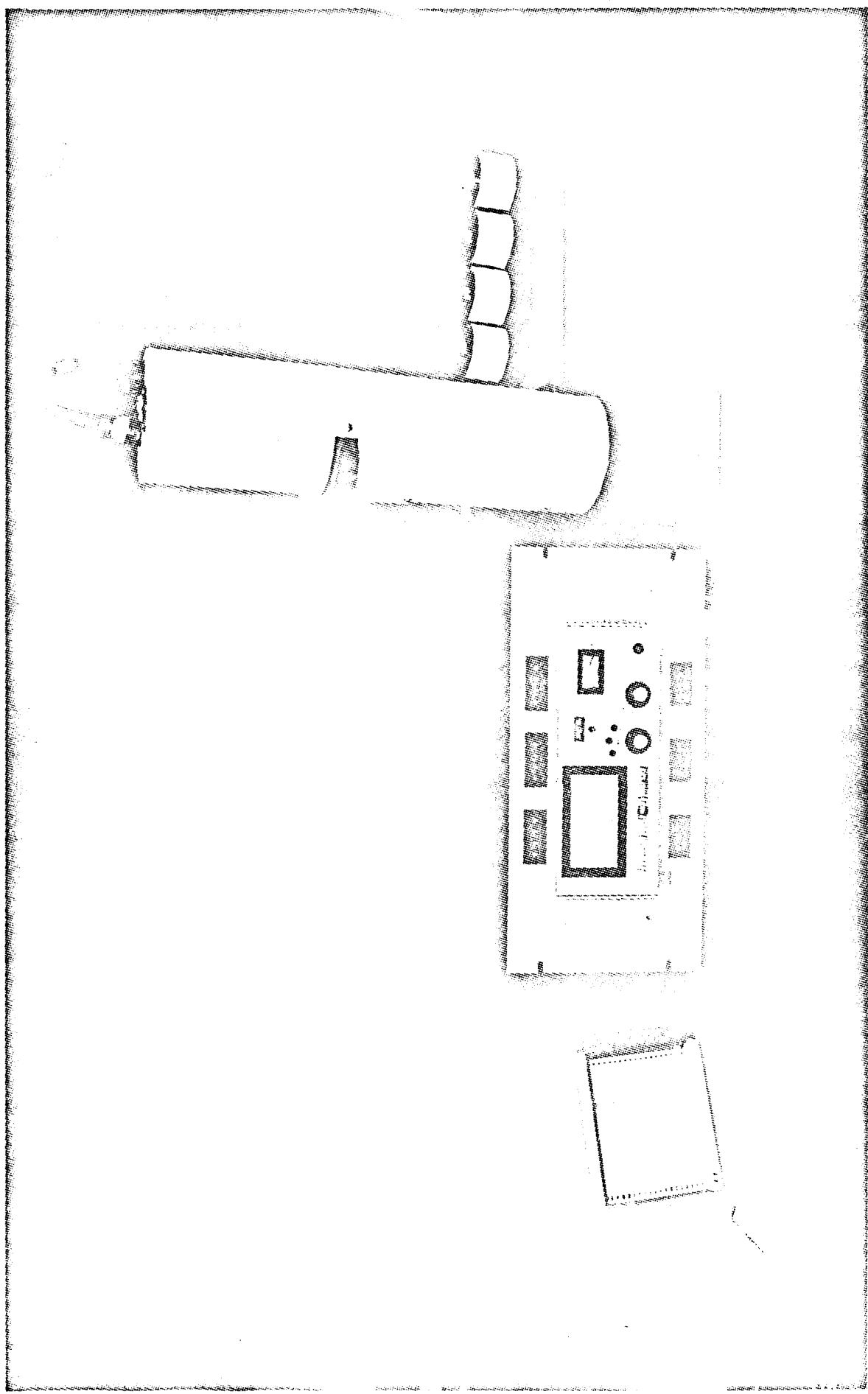
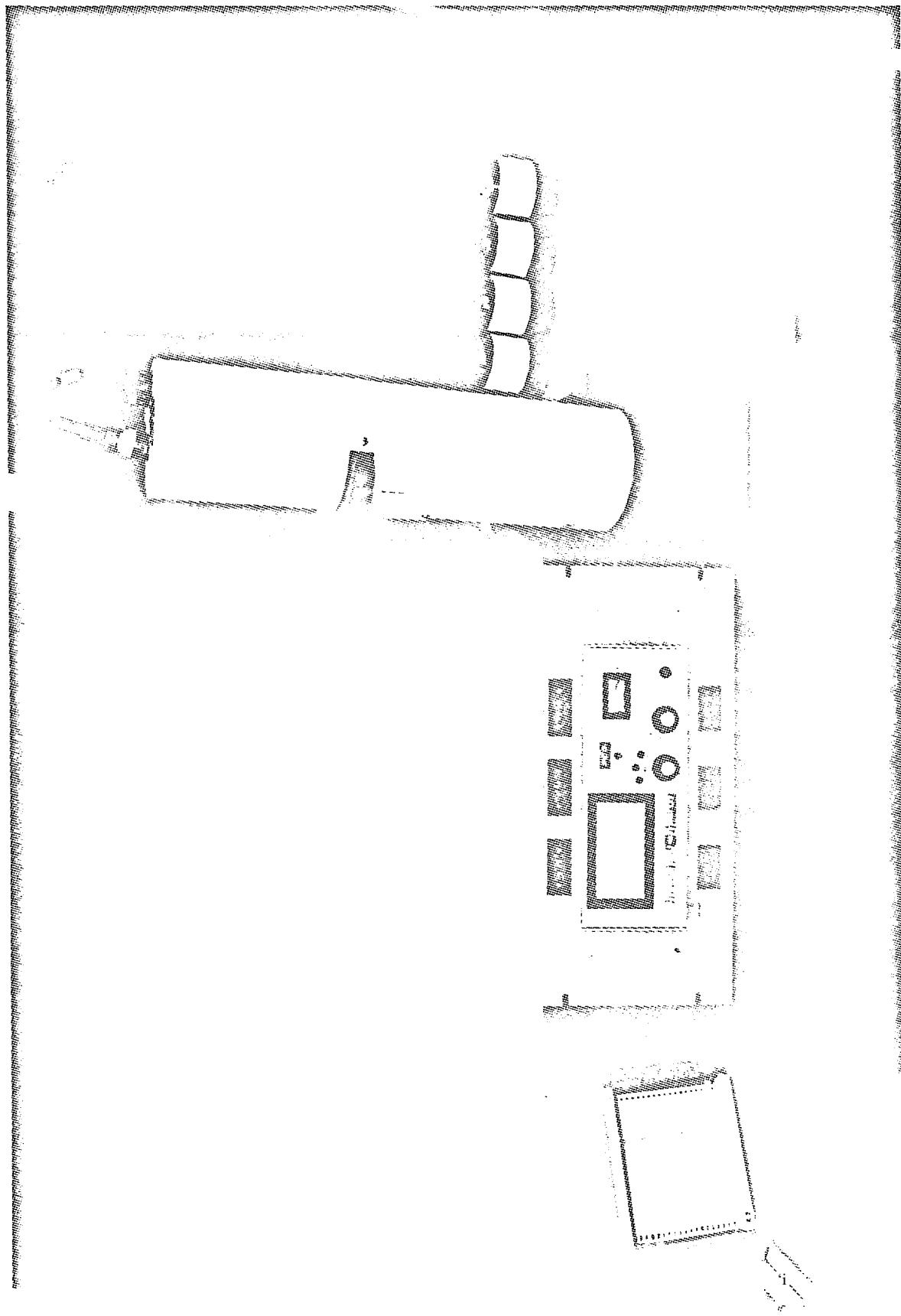


Fig. 2

Fig. 3





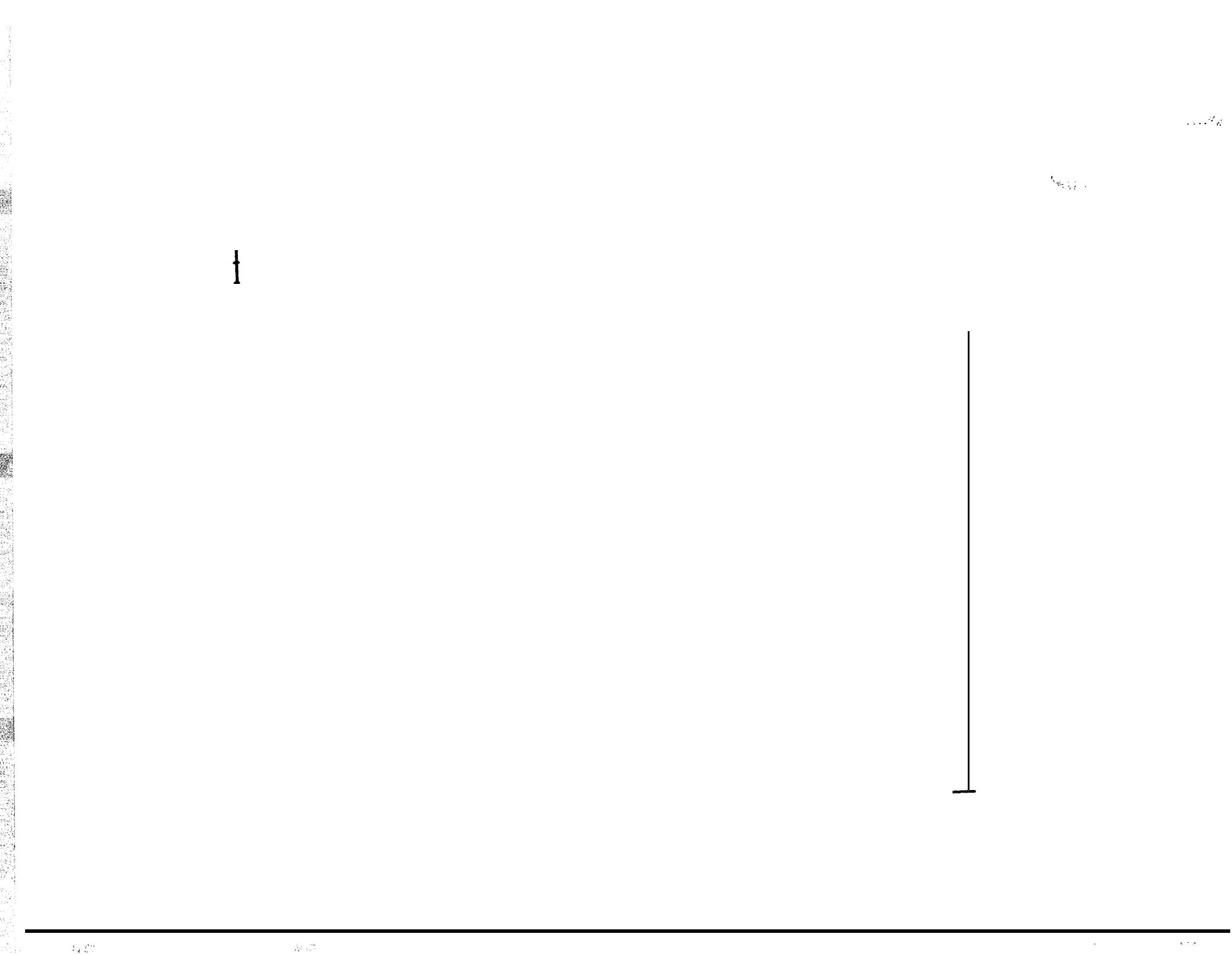
Computer calibrations giving voltage output versus equivalent black body temperature (Eq. 2) are displayed in Figs. 4, 5, and 6. The labels indicate the spectral pass bands and voltage range.

To complete the relationship between voltage output and equivalent black body temperature (Figs. 4, 5, and 6) and equivalent black body temperature and radiance tables 1 and 2 are appended.

RESULTS

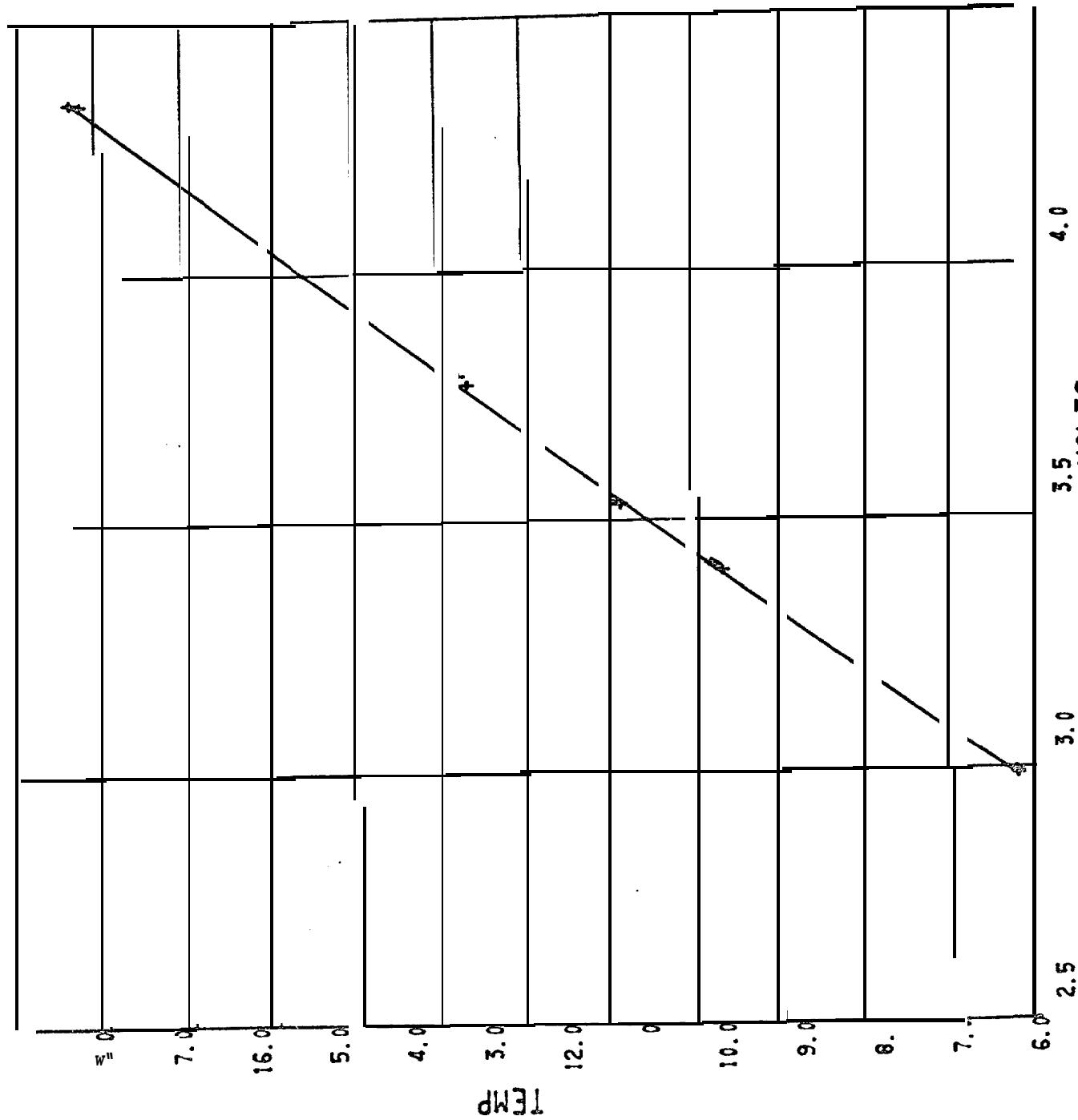
Four oil samples (Bunker-C, Kuwait Crude, Louisiana Crude and Fuel Oil No. 2} were temperature stabilized at room temperature ($\sim 20.0^{\circ}\text{C}$) in containment rings over sea water at the same temperature for the radiometer scans. The equivalent black body temperature of the overhead laboratory ceiling averaged a steady 23.5°C . This is important due to oil reflection of the ceiling (sky) radiance into the radiometer system.

To summarize the test method, four OCSEAP furnished oil samples were scanned over two widely separated "sea" temperatures in three spectral pass bands. Oil samples were scanned immediately following a synthetic spill of room temperature oil and 24 hours after the spill. In each case an observation termed the "delta factor" was the output of the tests. Simply put, the delta factor is the oil temperature minus the sea temperature. It is a measure of the temperature variation of different types of oil from the sea temperature and reflects the emissivity and thermal capacity of the oil on water.



MED SCALE CAL. 8-14 MICRONS

DEG = 2



4.5

4.0

3.5 VOLTS

3.0

2.5

FIG. 5

HISCALE CAL. 10-12 MICRONS

DEG = 2

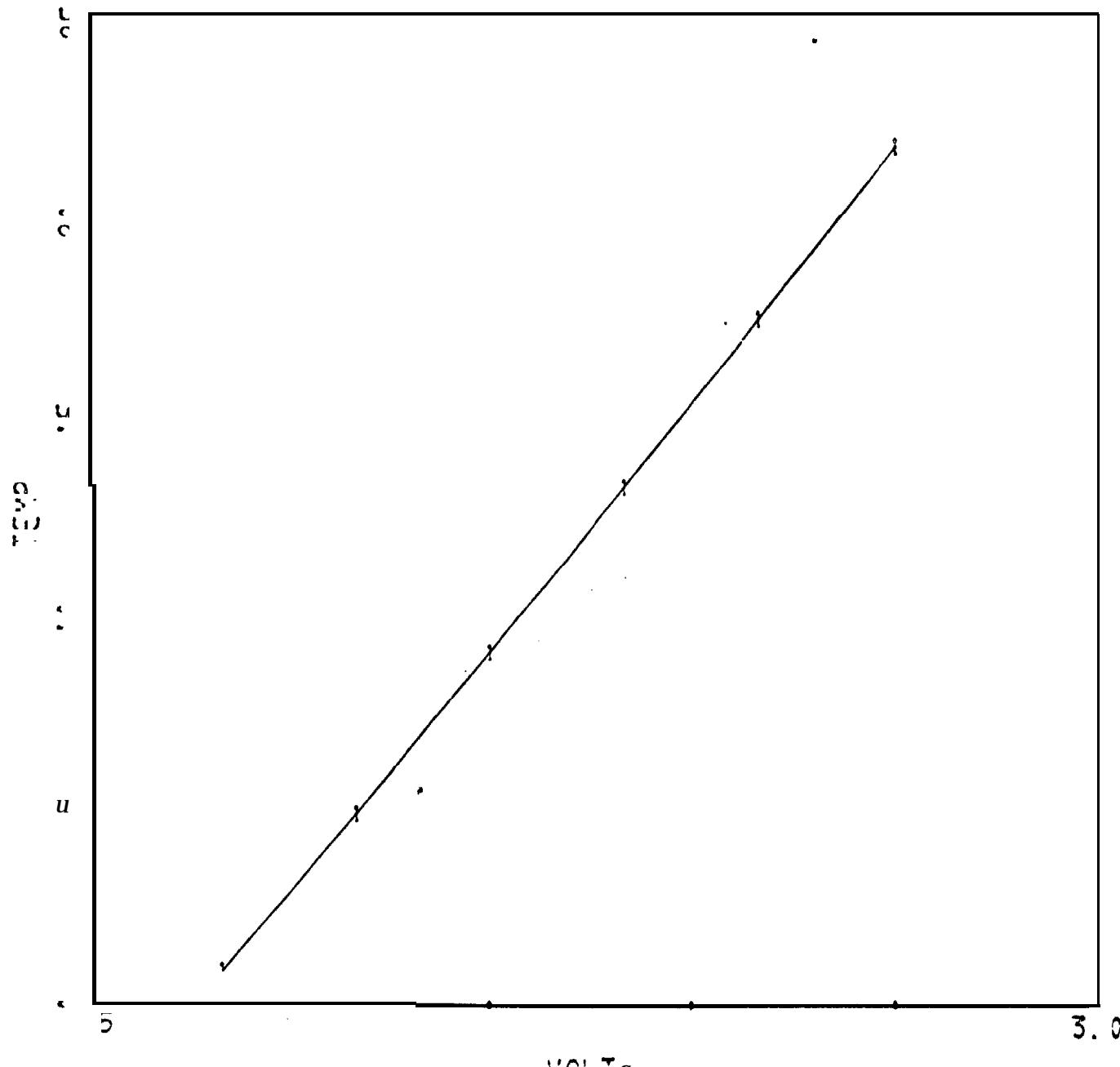


FIG. 6

Figure 7 displays the delta factor obtained in the 8-14 μm scans of the four types of oil. Singular is the large positive delta factor for Bunker-C oil over a "sea" surface of about 2C. Kuwait Crude also exhibits a moderately large factor at a "sea" temperature of 2C. The other two fuels do not evidence a significant change from water temperature especially when one realizes that real time observations at 1.0 km or more would mask delta factors that do not reach ± 1.0 degree. Reference to the same figure evidences the fact that a warm "sea" temperature of 19C results in an inconspicuous delta factor for Louisiana and Kuwait Crude and # 2 fuel oil. In fact, Bunker-C is only 1.6 C above the "sea" temperature. A 24 hr hold before a repeat scanning reduced the delta factor of the four oils even more.

Low-volatile-absorbing oil slicks such as formed by Bunker-C (heavy oil) display a delta factor much higher than the lighter more volatile oil type spills. This effect is certainly enhanced when the sea temperature becomes cold, approaching 2 to 4 C (Fig. 7). In fact the delta factor is 4 times as great for Bunker-C at 2C than at 19C. This effect is undoubtedly related to the higher absorptivity and thermal capacity of the heavy crudes over the lighter oils. To check this hypothesis, at least relative to absorptivity, the calculations from observations of the absorptivity (emissivity) over the 8-14 μm pass band are outlined.

Combs, Weickmann, Mader, and Tebo (1965) demonstrated a simple technique for determining the emissivity of various surfaces with a single-channel, fixed-field radiometer of an earlier type than

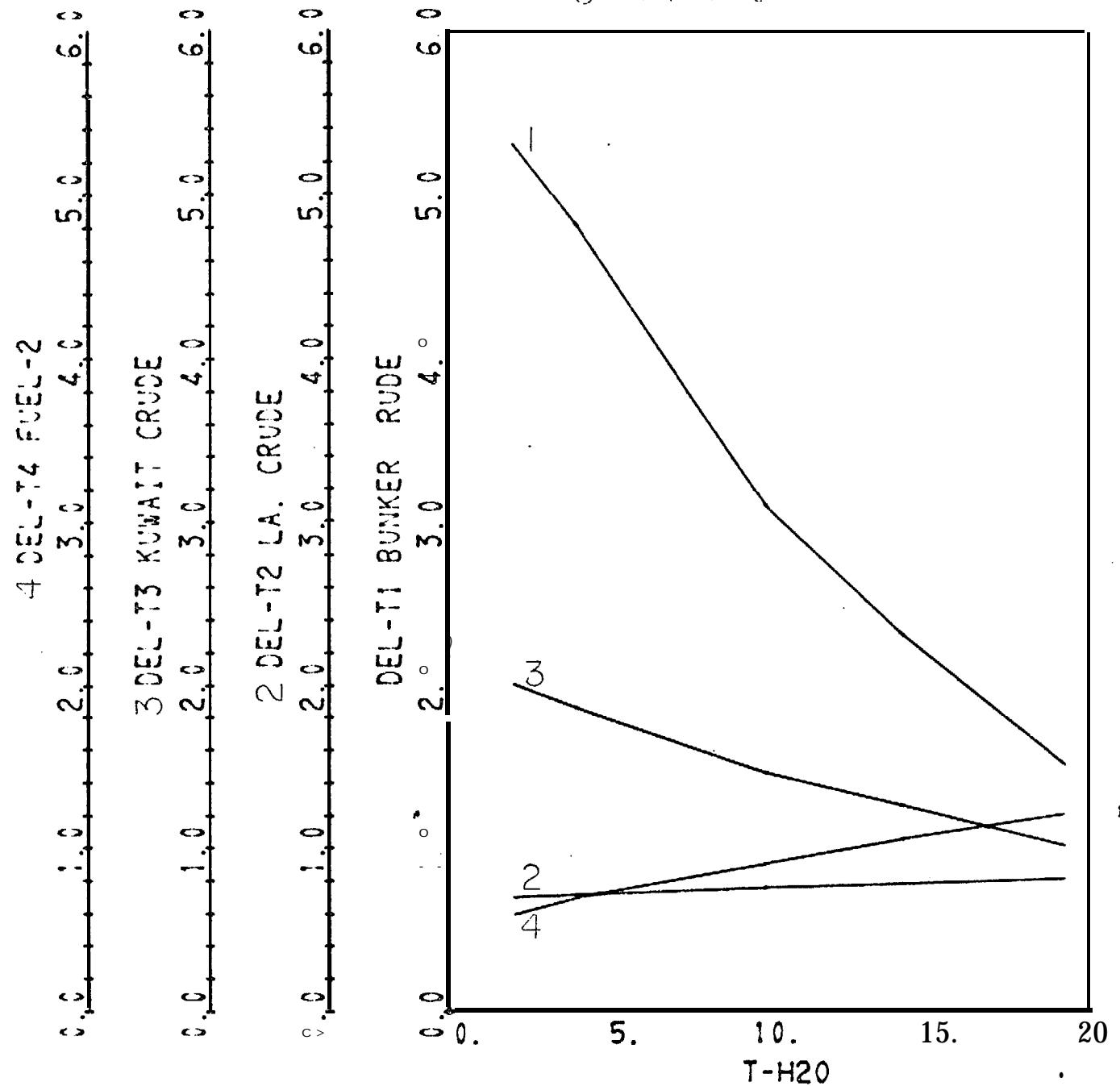


FIG. 7

that" employed in this research. If **radiometer** observations over the oil-are conducted without an integrating hemisphere shield and then with the shield, the effects of reflection of upper hemisphere or sky radiation are eliminated and one may define the oil emissivity by,

$$\epsilon_{\Delta\nu} = \frac{N_T^\uparrow - N^\downarrow}{N_o^\uparrow - N^\downarrow} \pm 0.15 \quad (3)$$

where $\Delta\nu$ covers the 8-14 μm pass band.

Observed temperatures, averaged over several scans for insertion in Eq. 3 follow:

$$N_T^\uparrow = .0035143 \text{ (8.2 C black body temp.)}$$

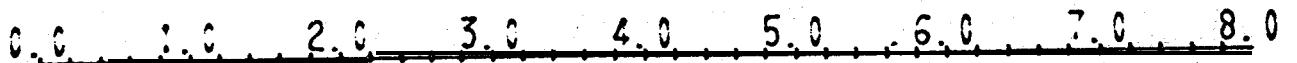
$$N^\downarrow = .0044632 \text{ (23.0 C black body temp.)}$$

$$N_o^\uparrow = .0034906 \text{ (7.8 C black body temp.)}$$

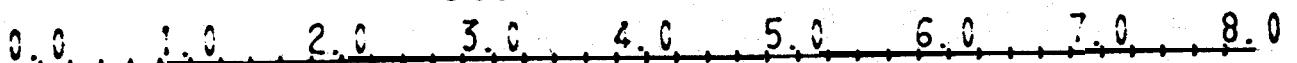
A solution of Eq. 3 with these inputs results in an **emissivity** for Bunker-C of $.976 \pm .02$. A similar solution for "sea" water resulted in an emissivity over the 8-14 μm band of $.945 \pm 015$. The random 1σ error limit of $.015$ makes these results somewhat tentative. However if one considers a standard error of estimate defined as one σ divided by the square root of the 10 observations the emissivity values are significant.

In the 10-12 μm pass band (Fig. 8) at approximately 19C, the delta factor for all oils is identical resulting in no type differentiation. However, at 2C Bunker Crude and # 2 fuel display large delta factors suggesting that the 8-14 μm spectral range would be a satisfactory pass band for identification of Bunker-C and possibly Kuwait Crude while the

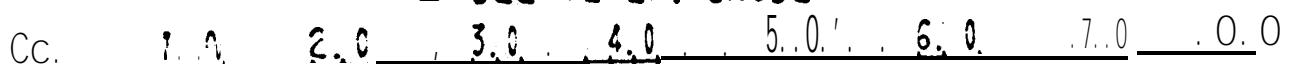
4 DEL-T4 FUEL-2



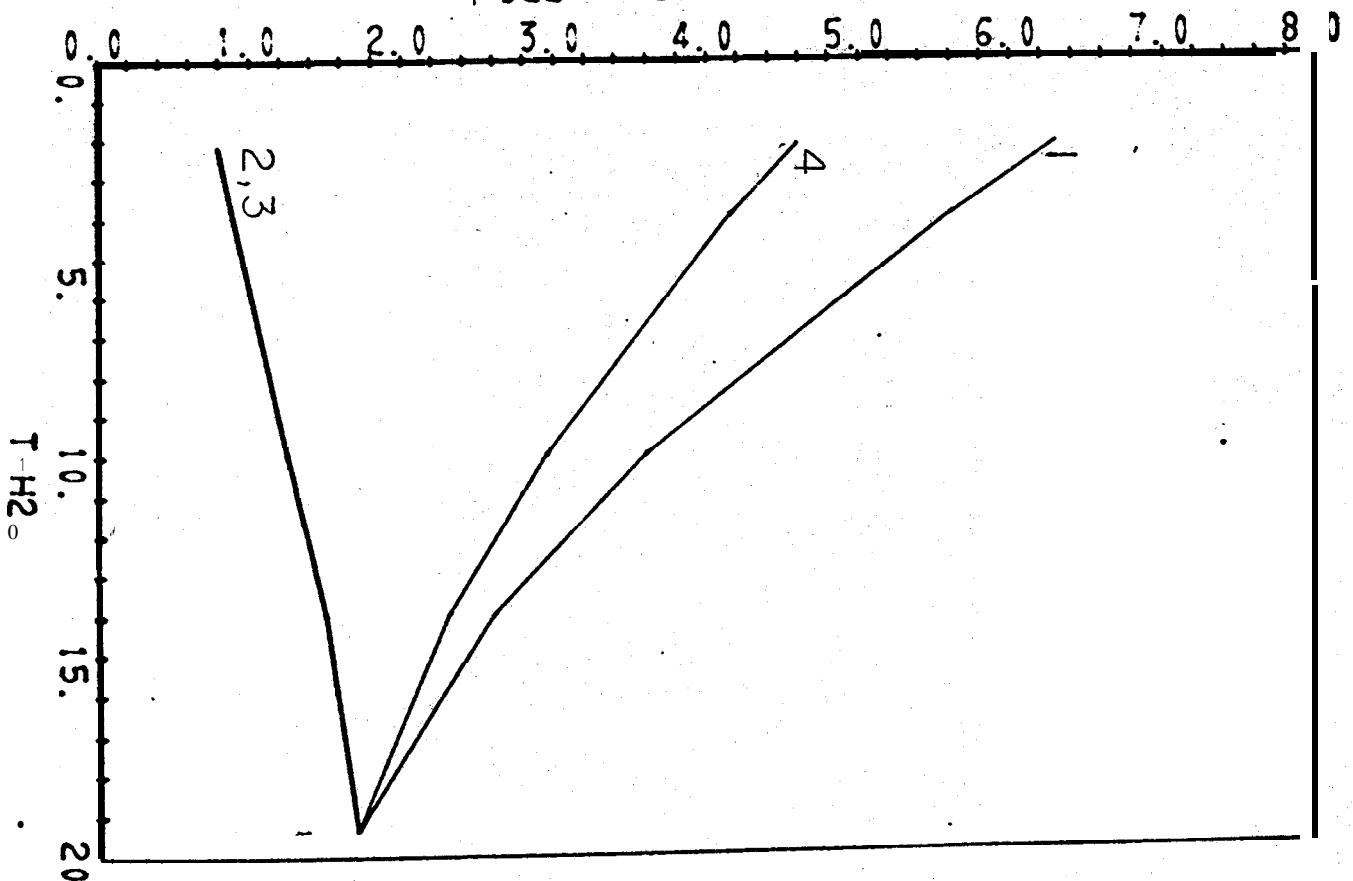
3 DEL-T3 KUWAIT CRUDE



2 DEL-T2 LA. CRUDE



1 DEL-T1 BUNKER CRUDE



10-12 μm band could be used for identification of # 2 as well as Bunker-C, Further review of these two figures suggest that it may be difficult to determine the extent of the Louisiana crude oil spill in view of the small delta factor at the 2C "sea" temperature.

Fig. 9 presenting results in the 10.5-11.5 μm band displays the largest delta factor again for both Bunker-C and # 2 fuel.

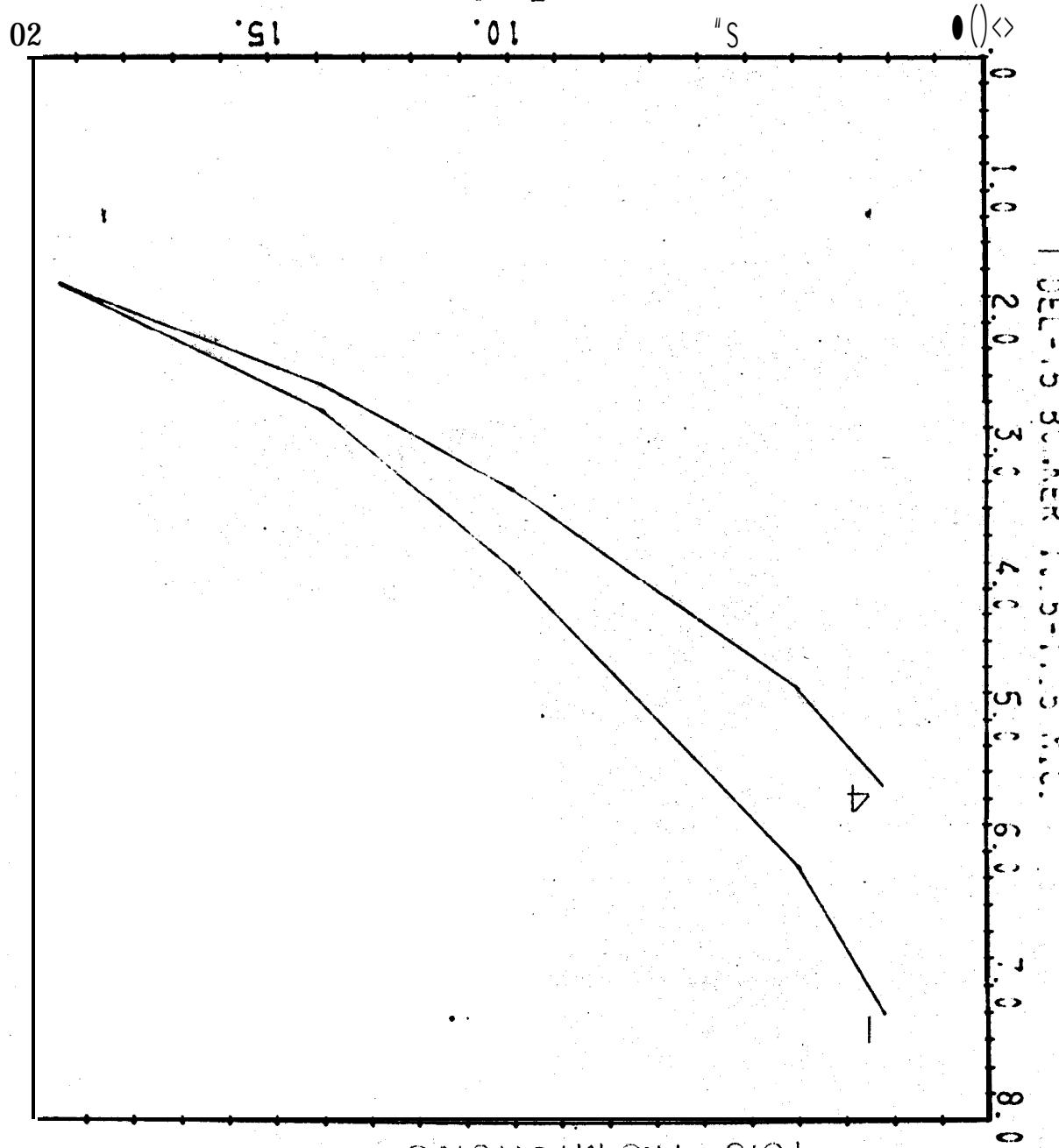
In some contrast to the Navy Report previously cited, our results do show a fair correlation of the radiometer delta factor with certain oil types in the two channels.

Figures 7 and 8 suggest that the 10 - 12 μm pass band better identifies Bunker-C and Fuel No. 2 at ~ 2 C while the 8 - 14 μm band better identifies Bunker-C and Kuwait crude at ~ 2 C. These same two figures clearly show that the 10 - 12 μm pass band is far superior to the 8 - 14 μm pass band in identifying a No. 2 fuel oil spill or slick. The results indicate a future more comprehensive and detailed interferometer or spectrometer study to determine the line structure of various oil types and thicknesses. This could possibly provide the pass bands or channels best suited to a particular oil type.

A singular feature (Fig. 9) became evident in the use of a "tighter" and cleaner pass band in the window region, namely 10.5 to 11.5 μm . This pass band increases the delta factor at a sea temperature of 2C suggesting strong emission in this band or a possible restrahlen effect. However, an interferometric laboratory search from 3.0 to 45.0 μm is again suggested for perhaps, 2C, 5C, 8C, 12C.

FIG. 9

T-H₂O



4 SEL-75 SUMMER 10.5-11.5 MM.

4 SEL-76 FUEL-2 : 0.5-1.5 MM.

Average thicknesses for the tests were 1 mm. Doubling and slightly exceeding the thicknesses (2 to 2.5 μ m) resulted in virtually" no change in the delta factor.

RESULTS SUMMARY

1. Laboratory tests indicate clearly that an oil-spill area is easily distinguished as to extent from the non-contaminated sea. This is certainly not an original conclusion.
2. There is a strong suggestion that unique IR signatures can be found for various oil types to enable good oil type identification.
3. Time after spill does not change the results as to identification of oil type. Obviously surface diffusion at the far boundaries of a spill will change this conclusion. The samples of this research represented more the "core" of the spill in a time series. The core area did not produce IR signature changes with time under the conditions imposed.
4. A thickness change of from 1 mm to 2.5 mm did not affect the IR signatures appreciably.

RECOMMENDATIONS

1. It would be very promising to conduct spectrometer or interferometric passive IR signature identification of various oil types. This could be a precise laboratory experiment followed by sea tests. Adequate 60K to 100K funds for proper equipment and filters are required. Surely this test will eventually be accomplished.
2. Continue on a larger scale and with IR imagery oil slick extent observations in the mixing conditions of the sea on targets of

opportunity or on a small lake. Ground truth is essential in a thickness to extent relation.

3. Thickness observations do not appear overly productive and seem to be outweighed by extent and **oil** type identification research.

SYMBOL TABLE

a_0 } quadratic coefficients for voltage
 a_1 } correction based on the temperature effect on chopper blade
 a_2 }

B **Planck** function

G radiometer electronics gain

k system response factor ($w \text{ cm}^{-2} \text{ sr}^{-1} \text{ volt}^{-1}$)

N sky radiance

No true black body radiance of oil interface under integrating sphere.

'R reference cavity radiance

'T "oil target black body radiance without integrating sphere

'E temperature offset voltage

V." output voltage analog

v wave number

ϕ transmission through lens and filter

σ transmission through detector

E emissivity

Δv spectral interval (wave)

REFERENCES

- Development of a prototype airborne oil surveillance system, Final Report No. CG-D-90-75, Task No. 4204.4/1, U. S. Navy, Office of Research and Development, 1975.
- Combs, A. C., H. K. Weickmann, C. Mader and A. Tebo: Application of Infrared Radiometers to Meteorology, J. Appl. Meteor., Vol. 4, No. 2, 1965.

FISCAL SECTION

Available Transfer Funds - OCSEAP TO APCL

CONVAIR 990 IMAGERY	3500
IR-UV LAB TEST	<u>15000</u>
	18500

Funds Expended by 9-30-76

CONVAIR 990 IMAGERY	3500
ALASKA (WELLER) IMAGERY OUT OF BARROW	<u>9500</u>
	13000

Funds Expended by 7-31-77

ON IR-UV	3500
	<u>3500</u>
	16500

Actual Received from OCSEAP thru 9-30-76	12100
COST TO APCL	- 410Q

FIGURE LEGEND .

1. Laboratory set-up including oil spill in confinement trays, radiometer head and console, digital and analog recorders.
The four sample containers of the OCS oil furnished for the experiment are shown in the right background.
2. Laboratory set-up to measure oil spill temperature including experimental tray described in Fig. 1, radiometer platform and recorder.
3. Same as Fig. 2 with 8 channel radiometer on platform.
- 4,5,6. Computer calibrations, voltage output versus black body temperature for selected ranges and spectral pass bands of radiometer.
7. Delta factor, 8 - 14 μm
8. Delta factor, 10 - 12 μm
9. Delta factor, 10.5 - 11.5 μm

TABLES

1. 8 - 14 μm black body tables
2. 9.5 - 11.5 μm black body tables

DATE,

CALCULATED, MM/YY PAGE

WAVE LENGTH REGION FROM 7.58 TO 15.38 MICRON WITH FILTER = PRT-5 8-14
 WAVE NUMBERS FROM 650.00 TO 1320.00 BY 10.00

BB CALIB RADIANT POWER FOR 6 LAYERS

PRESSURE	TEMP.	MIX RATIO	DELTU	IRRADIANCE W/SQ CM	ANGLE W/SQ CM	RADIANCE W/SQ CM SR	CO ₂ GM/SQ CM	H ₂ O GM/SQ CM
TEMP.		IRRADIANCE W/SQ CM		RADIANCE W/SQ CM SR	RADIANCE (NORMAL)			
.0	c.			.0031468	.0000681			
.2	c.			.0031577	.0000684			
.4	c.			.0031687	.0000685			
.6	c.			.0031796	.0000689			
.8	c.			.0031905	.0000691			
1.0	c.			.0031016	.0000693			
1.2	c.			.0031127	.0000695			
1.4	c.			.0031237	.0000698			
1.6	c.			.0031348	.0000701			
1.8	c.			.0031459	.0000703			
2.0	c.			.0031571	.0000705			
2.2	c.		J, 316-8-2		.0000708			
2.4	c.			.0031794	.0000711			
2.6	c.			.0031906	.0000713			
2.8	c.			.0032018	.0000716			
3.0	c.			.0032131	.0000718			
3.2	c.			● tic3??44	.0000721			
3.4	c.			.0032357	.0000723			
3.6	c.			.0032470	● dC;072b			
3.8	c.			.0032564	.0000729			
4.0	c.			.0032697	● UODJ: 31			
4.2	c.	*		.0032811	● OCGG 774			
4.4	c.			.0032926	.0000736			
4.6	c.			.0033460	● m J m / 3 9			
4.8	c.			.0033155	● .0000741			
5.0	c.			.0033270				
5.2	c.			.0033385	.0000746			
5.4	c.			● IIJ335LII	.0000749			
5.6	c.			.0033616	● oll Gu/5z			
5.8	c.			.0033732	.0000754			
6.0	c.			.0033849	● J 006 757			
6.2	c.			.0033965	.0000759			
6.4	c.			.0034082	.0000762			
6.6	c.			.0034199	● Q~Qc755			
6.8	c.			.0034316	.0000767	"		
7.0	c.			.0034433	.0000770			
7.2	c.			.0034551	.0000773			
7.4	c.			.0034669	.0000776			
7.6	c.			.0034787	● JUOJ 779			
7.8	c.			.0034906	● uCL; 7?3			
8.0	c.			.0035024	● fi,(3c 793			
8.2	c.			.0035143	.0000786			
8.4	c.			.0035262	.0000788			
8.6	c.			.0035382	.0000791			
8.8	c.			● C: 355:1	.0000794			
9.0	c.			● IIG356?1	.0000795			
9.2	c.			.0035741	.0000799			
9.4	c.			.0035862	.0000802			
9.6	c.			.0035982	● uGu:e. G5			
9.8	c.			.0036153	● Gcjj; ql17-			

*

STAT DATE,

HAVE LENGTH REGION FROM 7.58 TO 15.38 MICRONS WITH FILTER = PRT-5 8-14
 HAVE NJ MBERS FFCM 650.00 TO 1320.00 BY 10 *GO

BB CA LIB RADIANT POWER FOR 0 LAYERS

PRESSURE	TEMP.	MIX_RATIO	O ELU	IRRADIANCE	ANGLE	RADIANCE	CO ₂	H ₂ O
TEMP.	IRRADIANCE	RADIANCE	RADIANCE	W/SQ CM SR	W/SQ CM SR	GM/SQ CM	GM/SQ CM	
	W/SQ CM	W/SQ CM SR	(NORMAL)					
10.0	G.		.0036225	.0000810				
10.2	G.		.0036346	.0000813				
10.4	O.		.0036468	.0000815				
in.info			.0030589	.000081	8			
10.8	O.		.0036712	.0000821				
11.0	e.		.0036834	.0000824				
11.2	O.		.0036957	.0000826				
11.4	O.	"	● J 3 J 3 7 J 7 Y.	.0000829				
11.6	O.	"	.0037203	.0000832				
11.8	O.		.0037326	.0000835				
12.	O.		.0037450	.0000837				
12.2	O.		.0037573	.0000840				
12.4	O.		.0037698	.0000843				
12.6	O.		.0037822	● UOC:9kb				
12.8	O.		.0037946	● UC OC18+8				
13.	O.		.0038071	.0000851				
13.2	O.		.0038196	.0000854				
13.4	O.		.0038322	● OOOJ 857				
13.6	O.		● cl J3!+47	.0000858				
13.8	O.		.0038573	.0000862				
14.0	O.		.0038699	.0000865				
14.2	J.		.0038826	.0000868				
14.4	O.		.0038952	● Doo. 871				
14.6	O.		.0039079	.0000874				
14.8	O.		● da3732C6	● UUO: 87?				
15.0	O.		● OJ3334	.0000879				
15.2	O.		, 0 ; 3 9 - 6 1	.0000882				
15.4	O.		.0039589	.0000885				
15.6	O.		.0039717	.0000888				
15.8	J.		.0039845	● CJOG: 881				
16.0	O.		.0039974	.0000894				
16.2	O.		.0040163.0000	897				
16.4	O.		.0040232	.0000890				
16.6	O.		.0040361	.0000892				
16.8	O.		.0040461	● OOL:Q15				
17.0	O.		.0040621	.0000898				
17.2	O.		.0040751	.0000911				
17.4	O.		.0040881	.0000914				
17.6	O.		.0041012	.0000917				
17.8	O.		.0041143	.0000920				
18.0	O.	"	".0041274	.0000923				
18.2	O.	"	.0041405	.0000925				
18.4	O.	"	.0041537	.0000929				
18.6	O.	"	.0041668	.0000932				
18.8	O.	"	.0041800	.0000935				
19.0	O.	"	● 0041Y33	.0000938				
19.2	O.	"	.0042065	.0000941	"			
19.4	O.	"	.0042198	.0000944				
19.6	O.	"	.004243	.0000946				
19.8	O.	"	.0042465	● CC G:949				

STA 1, DATE,

WAVE LENGTH REGION FROM 7.58 TO 15.38 MICRONS WITH FILTER = PRT-5 8-14

WAVE NUMBERS FROM 650.00 TO 1320.00 + 10.00

BB CALIB RADIANT POWER FOR 6 LAYERS

PRESSURE	TEMP.	MIX RATIO	DELU	IPRADIANCE W/SQ CM	ANGLE W/SQ CM	RADIANCE W/SQ CM SR	CO ₂ GM/SQ CM	H ₂ O GM/SQ CM
TEMP.	IRRADIANC E W/SQ CM	RADIANCE W/SQ CM SR	RADIANCE (NORMAL)					
20.0	C.			• f2c14259a	.0000952			
20.2	C.			• 0342732	.0000955			
20.4	C.			• 0342866	.0000958			
20.6	C.			• 0343000	• OLG: 951			
20.8	C.			• 0343135	.0000954			
21.0	C.			• 0343270	.0000957			
21.2	C.			• 0343405	.0000970			
21.4	C.			• 0343540	.0000974			
21.6	C.			• 0343676	.0000977			
21.8	C.			• 0343812	.0000980			
22.0	C.			• 0343948	.0000983			
22.2	C.			• 0344084	.0000986			
22.4	C.			• i) G4h Z21	.0000989			
22.6	C.			• 0344358	.0000992			
22.8	"			• 90 f44632	.0000995			
23.0	C.				• LIL: L993			
23.2	C.			• 0344776	.0001001			
23.4	C.			• 0344958	.0001004			
23.6	C.			• 0345046	.0001007			
23.8	C.			• 0345184	.0001010			
24.0	C.			• 0345323	.0001013			
24.2	C.			• 0345462	• Goc1: 16			
24.4	C.			• J. h56J1	.0001020			
24.6	C.			• 0345740	• -rJii: 2" 3---			
24.8	C.			• 0345880	.0001025			
25.0	"			• 0346020	• UGLI: U29"			
25.2	C.			• 0346160	• tJOLit32			
25.4	C.			• 0346300	.0001035			
25.6	C.			• 0346441	.0001038			
25.8	C.			• 0346582	.0001042			
26.0	C.			• 0346723	.0001045			
26.2	C.			• 0346864	.0001048			
26.4	C.			• 0347006	.0001051			
26.6	C.			• 0347148	.0001054			
26.8	C.			• Gu4729G	• LIULLL57			
27.0	C.			• 0347432	.0001051			
27.2	C.			• 0347575	• CC C1: 64			
27.4	C.			• 0347718	.0001067			
27.6	C.			• 0347861	.0001070			
27.8	"			• 0348004	• OOG1U73			
28.0	C.			• 0348148	.0001077			
28.2	C.			• 0348292	• C. 101080			
28.4	C.			• 0348436	.0001093			
28.6	"			• 0348580	• J 0 : 1 D 85			
28.8	C.			• 0348725	.0001099			
29.0	C.			• 0348870	• OOJI: 93			
29.2	C.			• Jd4' 3015	.0001105			
29.4	C.			• 0349160	• MLI: 1099			
29.6	C.			• 0349306	.0001102			
29.8	C.			• 0349452	.0001106			

WAVE LENGTH REGION FROM 9.25 TO 11.90MICRONS WITH FILTER = BE LICKA + DET
 WAVE NUMBERS FROM 84 J.00 TO 1080.00 BY 10.00 BB CALIB RADIANT POWER FOR 6 LAYERS

PRESSURE	TEMP.	MIX RATIO	DELU	IRRADIANCE W/SQ CM	ANGLE	RA DIANCE W/SQ CM SR	CO ₂ GM/SQ CM	H ₂ O GM/SQ CM
	TEMP.	IR-RAD IANG E W/SQ CM	RADIANCE W/SQ CM SR	RADIANCE (NORMAL)				
0	0.	-	• 0006229	• 000670				
.2	0.	-	• 0006252	• 000673				
.4	0*	-	• 0006275	• 000675				
.6	0.	-	• 0006299	• 000678				
.8	0.	-	• 0006322	• 000680				
1.0	C.	-	• 0006345	• 000683				
1.2	0.	-	• 0006359	• 000685				
1.4	G.	-	• 0006392	• 000688				
1.6	0.	-	• 0006416	• 000690				
1.8	0.	"	• 0006440	• 000693				
2.0	0.	-	• 0006463	• 000695				
.2	0.	-	• 0006487	• 000698				
2.4	0.	-	• 0006511	• 000700				
2.6	0.	-	• 0006535	• cLG. d7u3				
2.8	0.	-	• 0006558	• 000705				
3.0	0.	-	• 0006582	• 000708				
3.2	C.	-	• 0006606	• 000711				
3.4	0.	-	• 0006630	• 000713				
3.6	0.	-	• 0006654	• 000716				
3.8	5.	-	• 0006679	• 000719				
4.0	0.	-	• 0006727	• 000721				
4.2	0.	-	• 0006751	• 000724				
4.4	0.	-	• 0006776	• 000729				
4.6	0.	-	• 0006800	• 000732				
4.8	0.	-	• 0006824	• 000734				
5.0	0.	"	• OJU6824	• 000734				
5.2	0.	-	• OJCF3549	• 000737				
5.4	0.	-	• 0006847	• 000739				
5.6	0.	-	• 0006898	• COO G742				
5.8	0.	-	• 0006925	• 000745				
6.0	0.	-	• 0006948	• 000747				
6.2	0.	-	• 0006972	• 000750				
6.4	0.	-	• 0006997	• uIJO?53				
6.6	0.	"	• oJ07Lz2	• 000755				
6.8	0.	-	• oGi!7047	• 000758				
7.0	0.	-	• 0007072	• 000761				
7.2	c.	-	• 0007097	• 000764	I	"		
7.4	0.	-	• 0007122	• 000765				
7.6	0*	-	• 0007147	• 000769				
7.8	0.	-	• 0007173	• OOJL 772				
8.0	c.	-	• OJu7i98	• OJG 774				
8.2	0.	-	• C7-72 23	• 000777				
8.4	0.	-	• 0007249	• 000780				
8.6	6"	G.	• 0007274	• 000783				
9.0	0.	-	• 0007299	• 000785				
9.2	J.	-	• 0007325	• ud2; 788				
9.4	0.	-	• 0007351	• 000791				
9.6	0.	-	• 0007376	• 000794				
9.8	0.	-	• 0007402	• 000796				
9.8	0.	-	• 0007428	• 000799				

WAVE LENGTH REGION FROM 9.26 TO 11.90 MICRONS WITH FILTER = BE LICKA + DET
 NAVES NUMBER FROM 840.00 TO 1080.00 BY 10.00 BB CALIB RADIANT POWER FOR 0 LAYERS

PRESSURE	TEMP.	MIX RATIO	DELU	IRRADIANCE W/SQ CM	ANGLE	RADIANCE W/SQ CM SR	CO2I GM/SQ CM	H2O GM/SQ CM
TEMP.	IRRADIANCE W/SQ CM			RADIANCE W/SQ CM SR	RADIANCE (NORMAL)			
10.0	0.			.0307453	.0000802			
10.2	0.			.0307479	.0000805			
10.4	0.			.0307505	.0000807			
10.6	00			.0307531	.0000810			
10.8	0.			.0307557	● OG00813			
11.0	0.			● Oti07583	.0000815			
11.2	0.			.0307609	.0000819			
11.4	0.			.0307636	.0000821			
11.5	0.			.0307662	.0000824			
11.8	0.			.0307688	.0000827			
12.0	0.			.0307714	.0000830			
12.2	c*			.0307741	.0000833			
12.4	G.			.0307767	.0000836			
12.6	C.			.0307794	.0000838			
12.8	0*	● U : U	7.8 2.0	.0307841	.0000841			
13.0	0.			.0307847	.0000844			
13.2	0.			.0307874	.0000847			
13.4	G.			.0307903	.0000850			
13.5	C.			.0307927	.0000853			
13.9	0.			.0307954	.0000856			
14.0	C.			.0307981	.0000859			
14.4	0.			.0308008	.0000862			
14.4	0.			.0308035	.0000864			
14.6	0.			.0308062	.0000867			
14.8	0.			.0308089	.0000870			
15.0	0.			.0308116	.0000873			
15.2	C.			.0308143	.0000875			
15.4	0.			.0308171	● o o C 8 7 9			
15.6	C.			.0308198	.0000878			
15.8	C.	7 m	2 2 . 5	.0308225	.0000885			
16.0	0.			.0308253	● cG@;b18			
16.2	c.	"	"	● 3;29Z80	.0000891			
16.4	C.	"	"	● O<LdZ28	.0000894			
16.6	0.	"	"	.0308335	.0000897			
16.8	0.			.0308363	.0000900			
17.0	C.			.0308391	.0000913			
17.2	o*			.0308419.0000915				
17.4	0.			.0308446	.0000919			
17.6	G.			.0308474	.0000912			
17.8	0.			.0308502	.0000915			
18.0	U.			.0308530	.0000918			
18.2	0.			.0308558	.0000921			
18.4	U.			.0308586	.0000924			
18.6	C.			.0308614	.0000927			
18.8	0.			● CLU8543	.0000930			
19.0	0.			.0308671	● ovGb933			
19.2	0.			.0308699	.0000935			
19.4	0.			.0308727	m +			
19.6	0.			.0308756	.0000942			
19.8	0.			● ; ZC8784	.0000945			

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WAVELENGTH PEG ION FROM 9.26 TO 11.90 MICRONS WITH FILTER = BELICKA + UET
 WAVE NUMBERS FROM 840.00 TO 1080.00 BY 1.00

BB CALIB RAD IANT POWER FOR 6 LAYERS

PRESSURE	TFMP.	MIX RATIO	DELU	IRRADIANCE	ANGLE	RADIANCE	CO2	" do "
TEMP.				W/SQ CM		W/SQ CM SR	GM/SQ CM	GM/SQ CM
					RADIANCE	(NORMAL)		
20.0	O.			•0008813	•0000948			
20.2	G.		"	•0008841	•0000951			
20.4	O.			•0008870	•0000954			
20.6	O.			•0008899	•0000957			
20.8	G.			•0008928	•0000960			
21.0	O.			•0008956	•0000964			
21.2	O.			•0008985	•0000967			
21.4	O.			•0009014	•0000970			
21.6	J.			•0009043	•0000973			
21.8	O.			●C3G3372	•0000976			
22.0	G.			•0009101	•0000979			
22.2	O.		"	•0009130	•0000982			
22.4	G.			•0009159	•0000985			
22.6	J.			•0009159	•0000989			
22.8	O.			•0009218	•0000992			
23.0	O.			•0009247	•0000995			
23.2	G.			•0009277	•0000998			
23.4	O.			•0009306	•0001001			
23.6	O.			•0009336	•0001004			
23.8	O.			•0009365	•0001008			
24.0	O.			•0009395	•0001011			
24.2	L.			•0009425	•0001014			
24.4	G.			•0009454	•0001017			
24.6	J.			•0009484	•0001020			
24.8	CO			•0009514	•0001024			
25.0	G.			•0009544	•0001027			
25.2	G.			●51 C9574	•0001030			
25.4	O.			•0009604	•0001033			
25.6	G.			●09 U?L34	•0001035			
25.8	G.			•0009664	•0001040			
26.0	C.			•0009694	•0001043			
26.2	L.			●QG09724	•0001046			
26.4	G.			•0009755	•0001049			
26.6	G.			•0009785	•0001053			
26.8	G.			•0009815	•0001056			
27.0	G.			•0009846	•0001059			
27.2	G.			•0009876	•0001063			
27.4	O*			•0009907	●OG.1u65			
27.6	C.			●C'Jb 9%37	●LO CI?69			
27.8	O.			•0009968	•0001072			
28.0	O.			•0009999	•0001076			
28.2	J.			•0010030	•0001079			
28.4	J.			•0010060	●OGC1C52			
28.6	"			•0010091	•0001085			
28.8	O.			●OG1122	•0001089			
29.0	O.			•0010153	•0001092			
29.2	O.			•0010184	•0001095			
29.4	J.			•0010215	•0001099			
29.6	O.			●C1J246	•0001102			
29.8	O.			•0010278	•0001106			